



PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Andrew Capon et al.

For: MULTI-STAGE RESPIRATOR FILTER WITH TIM FILTER OPTION

Serial No.: 10/604,497

Examiner: Mital B. Patel

Filed: 07/25/2003

Art Unit: 3743

Docket No.: 71619-0006

Commissioner for Patents
Alexandria, VA 22313-1450

Sir:

DECLARATION UNDER 37 C.F.R. § 1.132 OF DAVID PIKE

David Pike declares and says that:

1. I am a citizen of the United Kingdom, a resident of Salisbury, Wiltshire, United Kingdom, and am an inventor named in the above-identified U.S. Patent Application.
2. I graduated from Salisbury College with a Higher National Certificate in Microbiology, Physiology (with Pharmacology) and Biochemistry in 1964. Except for a two year National Service in the Royal Air Force, I have been continuously employed for more than fifty years in the defence industry, either for the British Government or in private industry, in the development of personal protection equipment for use by the Services against nuclear, biological and chemical (NBC) agents, and more recently against toxic industrial materials (TIMs), also sometimes known as toxic industrial chemicals (TICs). Since 1979, I have been responsible for the development of General Service Respirators, including filters used on such respirators. As a result of my educational and employment background, I believe that I am a person of at least ordinary skill in the field of defence respirators, in general, and in filter media for such respirators, in particular. My Curriculum Vitae is attached hereto as Exhibit A.

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3. More recently, I have been employed as a consultant to Avon Technical Products in the United Kingdom in the development of gas masks for the United States Department of Defense (DOD), Joint Services General Purpose Mask (JSGPM). Avon has been awarded a contract by the DOD for development and manufacture of JSGPM.

4. The invention in the above-identified U.S. patent application solves a problem that has not heretofore been solved in any gas mask insofar as I am aware. The invention was developed in order to meet DOD requirements for the JSGPM. These DOD requirements for the JSGPM are set forth in the excerpts from the DOD document entitled: Performance Requirements Joint Services General Purpose Mask (JSGPM) dated 30 September 2003, attached hereto as Exhibit B ("JSGPM Performance Requirements document"). The requirements for the JSGPM set forth in JSGPM Performance Requirements document reflect the requirements for this mask at least as early as April 1998. The JSGPM Performance Requirements document shows the System Overview and the Operational Requirements for the four Services. The Operational Requirements include removal of TIMs for all Services. In particular, Table 5 shows the tests to be used for TICs. These TICs include fuming nitric acid, ammonia, carbon disulfide, ethylene oxide and formaldehyde. It was well understood to those persons who have ordinary skill in the art of respirator filters at least as of April 18, 2000, that these chemicals pose very significant problems for protection if only the military charcoals are used in a respirator. This problem contrasts strongly with the protection requirements for chemical warfare agents that are readily removed by military charcoals.

5. It is traditional for combination filters such as those used in industry or by military

to have two filter media in sequence. Firstly, a particulate filter removes solid or liquid aerosols, droplets, and particulate matter such as dust, smokes, bacteria, and viruses. The second medium is an adsorbent layer, usually an activated charcoal, to remove gases and vapors. A wide variety of charcoals with or without impregnates are available for particular filtration applications. It has also been known that the charcoal adsorbent may have more than one type of charcoal intermixed or filled as separate layers into the filter body.

6. Military filters typically have heretofore used two types of media, particulate and charcoal. The charcoal is impregnated with such metallic salts such as Cu, Ag, Zn, Mo, and triethylenediamine in order to broaden the scope of chemical filtration by including both physical adsorption and chemical interaction with the impregnants to remove those chemicals that are poorly adsorbed and retained by physical adsorption alone. This was the traditional state of the art in military filters at the time that the invention in the above identified application was made.

7. Attempts have been made in the past to develop a filter medium that has the capability to remove both particulate matter and to adsorb gases. These attempts are often referred to as "intimate mix" filters. One very good example of this type of filter was the "Cheekpad" design of filters used in the U.S. Military M17 Mask. However, the filtration efficiency of such media is not that great either for chemicals or for particulates and they are not commonly in use today.

8. The above-identified patent application relates to a primary military filter with the broad spectrum capability to remove particulate materials in the first filter medium encountered as air enters the filter, followed by an impregnated charcoal adsorbent. This filter does have a broad spectrum of adsorption and chemisorption and is useful against many toxic industrial

materials (TIM). However, in order to keep the weight and breathing resistance through the filter and mask as low as possible, the mass of charcoal used in the filters is limited and this presents a problem for protection against some TIMs. On the other hand, it is very effective in dealing with military chemical warfare gases and very acceptable to the war fighter.

9. In order to resolve the problem of protection against TIMs as required by the JSGPM Performance Requirements document, the invention provides a primary filter designed to remove the chemical warfare gases (charcoal layer) and includes a high efficiency particulate filter element for removing the biological and other aerosol materials in droplet or solid form. Further, according to the invention, a secondary filter is used to boost the protection against TIMs, when needed. Complete removal of any of the required list of TICs could only be achieved by the addition of a secondary filter attached on top of the primary filter. In this case, the secondary filter is designed to react with and remove chemicals such as ethylene oxide by use of an alternative adsorbent to the activated charcoal used in the primary filter as well as removal of any particulate TIMs. The secondary filter media can include activated charcoal or can be some other alternative adsorbent such as porous polymer, alumina or molecular sieve material that will remove TIMs, all of which were known to those persons who have ordinary skill in the art of respirator filters at least as of April 18, 2000.

10. According to the invention in the above-identified patent application, the military mask now has a primary filter that is attached to the mask for general military use, and when needed, a secondary filter that can optionally be attached as an add-on to the primary filter to boost performance against exposures to TIMs, should the gas mask user encounter such materials.

11. Turning now to the Klusewitz et al. U.S. Patent No. 3,142,549 (Klusewitz et al. '549), it discloses a respirator with a primary filter and a disposable pre-filter. The primary filter has both a high efficiency particulate filter and adsorption media such as activated charcoal. The disposable pre-filter is a particulate filter designed to reduce clogging of the high efficiency particulate filter and is not adapted to remove toxic industrial materials (TIMs) as that term is understood by a person of ordinary skill in the art of respirators at least as of April 18, 2000. There is no disclosure in the Klusewitz et al. '549 patent of a disposable prefilter or auxiliary filter that is adapted to remove TIMs. Although TIMs include some particulate materials that may be removed by the Klusewitz et al. '549 prefilter, a person with ordinary skill in the respirator art at least as of April 18, 2000 would not consider the Klusewitz et al. '549 prefilter to be a TIM filter media, i.e. adapted to remove TIMs, because of the failure of this prefilter to remove any of the gas components of TIMs. Further, it is quite clear to me that the Klusewitz et al. '549 prefilter does not have an adsorbent material and thus is not capable of removing the gaseous components of what are understood as TIMs by those persons that have ordinary skill in the art of respirators.

12. Attached hereto as Exhibit C are excerpts from a report published by the U.S. Department of Justice, National Institute of Justice, Law Enforcement and Corrections Standards and Testing Program entitled "*Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responder*," NIJ Guide 100-00, Volume 1 June 2000 (DOJ document). The DOJ document report makes reference on page 10 to a 1998 report entitled: "International Task Force 25 : Hazard from Industrial Chemicals Final Report." This report is a comprehensive report upon which the topic of TICs/TIMs has been based. The

DOJ document lists TIMs on page 12 in terms of high, medium and low levels of hazard. The DOJ document also gives a brief description of the chemical warfare agents and their physical and injurious properties. Although some of the TIMs listed in Exhibit C are particulate in form, the majority of them are gaseous materials, none of which will be removed by the auxiliary filter media 9 of the Klusewitz et al. '549 patent. Those persons who have ordinary skill in the art of respirator filters would know at least as early as April 18, 2000 that many TIMs are the gaseous materials that are listed in Exhibit C and would further know that the particulate auxiliary filter media 9 disclosed in the Klusewitz et al. '549 patent is not adapted for removal of any of the gases that form the bulk of the TIMs.

13. Attached hereto as Exhibit D are pages 1-17 of a document entitled "*Guidance for Filtration and Air-Cleaning Systems to Protect Building Environments from Airborne Chemical, Biological, or Radiological Attacks*," published by the Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupation Safety and Health, April 2003 (the DHHS document). The DHHS document discloses in general the various airborne materials which are of particular concern in the event of airborne chemical, biological, or radiological attacks. On pages 8-16, there is a discussion of filtration and air cleaning principles, including particulate air filtration and gas phase air cleaning. The graph entitled FIG. 1 "Common Air Contaminates and the Relative Sizes" which appears on FIG. 7 gives the spectrum of air contaminants and their relative sizes. In Section 3.1, beginning on page 8, the DHHS document discusses the concept of particulate air filtration. This type of filtration is the type of filtration to which Klusewitz et al. '549 auxiliary pre-filter is directed. Particulate filters in general remove only the particulate elements of the TIMs that are set forth in the DOJ

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document.

14. Gas phase air cleaning is discussed in the DHHS document, Section 3.2 pages 15 through 17. The filtration which is described in Section 3.2 of the DHHS document is not the type of filtration that is described in the Klusewitz et al. '549 patent auxiliary filter particulate filter medium 9.

15. For all of the reasons set forth above, it is my firm opinion that the Klusewitz et al. '549 patent does not disclose or suggest the invention which is claimed in claims 1-13 of the above-identified patent application.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Respectfully submitted,

Date: 29 November 2004

David W. Pike
 David Pike

G0146858

CV for David William Pike

9 January 1936 Born Chitterne, Wiltshire, England

Education

1940 – 1946 Dinton Infants School
1946 – 1952 Gillingham Grammar School
1954 – 1964 Salisbury College of Further Education (Part Time)
GCE A Level Botany, Zoology
Higher National Certificate in Microbiology, Physiology (with
Pharmacology) and Biochemistry

Work experience

1953 – 1954 Scientific Assistant at Microbiological Research Department
Biological Defence
1954 – 1956 2 Year National Service in Royal Air Force
1954 – 1961 Scientific Assistant at Microbiological Research Establishment,
Porton. Biological Defence
1961 – 1971 Experimental Officer at Protection Division, Chemical Defence
Establishment, Porton. Development of Mk 1, 2 and 3 NBC
Protective clothing for the UK Ministry of Defence
1971 Graduate of the Lieutenants Course at the Royal Naval College,
Greenwich
1971 – 1973 Senior Scientific Officer. Technical Staff Officer Planning at
Chemical Defence Establishment. Responsible for preparation
of the Annual Research Review and Research and
Development Reports.
1973 – 1979 Further work on personal protection equipment against
chemical, biological and nuclear threats
1979 – 1987 Principal Scientific Officer, Physical Protection Division,
Porton. Project Officer responsible for the development of the
S10 General Service Respirator and Filter currently in Service
use by the Ministry of Defence to provide protection to service
personnel against NBC agents.
1987 – 1997 Company Director Racal Panorama Limited, and Vice
President, Racal Filter Technologies Inc, Brockville, Ontario,
Canada. Responsible for research, development and production
contracts relating to gas mask filters. Major supplier of C2
filters to the US DOD and Canada, as well as other types
developed to meet the overseas requirements of such countries
as Netherlands, Sweden and others.
1997 - Present Self employed consultant on matters relating to Chemical,
Nuclear and Biological Defence. In particular work with Avon
Technical Products for the US DOD JSGPM Mask program
and other defence programs.



PERFORMANCE SPECIFICATION

JOINT SERVICE GENERAL PURPOSE MASK
(JSGPM)

30 September 2003



1.1 SYSTEM OVERVIEW

The *JSGPM system* is being developed to replace the M40/M42 series of *masks* for U.S. Army, U.S. Marine Corps ground and combat vehicle operations and the MCU-2/P series of masks for U.S. Air Force and U.S. Navy shore-based and shipboard applications. Additionally, the JSGPM will replace the M17A2 mask used by the U.S. Air Force and the M17, M25A1, and M45 Land Warrior masks used by the Army. The *JSGPM system* will be designed to provide 24 hours continuous head-eye-respiratory Chemical-Biological (CB), radiological particulates, and Toxic Industrial Material (TIM) protection, lower the weight and bulk, and improve overall mission performance of the wearer. The mask components will be configured to reduce the overall profile of the mask and to allow for improved integration with future soldier systems. The program will target the lowest possible life cycle cost and will be supported through a joint logistic system.

2. SYSTEM REQUIREMENT

2.1 OPERATIONAL REQUIREMENTS

The system shall be required to protect individuals in all mission scenarios including but not be limited to: in and around aircraft, vehicles, naval ships and crafts, fixed and mobile sites, and individuals in or transiting to and from a nuclear, biological, or chemical threat area (CTA).

ARMY

The JSGPM shall provide Army units with protective masks to provide for increased force protection. It shall protect against NBC *agents* as part of the *Mission Oriented Protective Posture (MOPP)* and increase combat effectiveness. The JSGPM shall be employed under all typical battlefield conditions expected during high, medium, and low intensity conflicts when employment of NBC weapons or exposure to toxic industrial chemicals is likely.

Air Force (AF)

The JSGPM shall provide the Air Force with protective masks to provide for increased force protection. It shall protect against NBC *agents* as part of the *MOPP* and thereby increase combat effectiveness. The AF requires the JSGPM to operate concurrently with other aircraft ground servicing tasks to include, but not limited to: aircraft refueling, loading and off-loading cargo, routine maintenance, preflight and post-flight inspections, and fleet servicing equipment and materials when employment of NBC weapons or exposure to toxic industrial chemicals is likely.

Marine Corps

The JSGPM shall provide Marine units with protective masks to provide for increased

force protection. It shall protect against NBC *agents* as part of the *MOPP* and thereby increase combat effectiveness. The JSGPM shall be employed under all typical battlefield conditions expected during high, medium, and low intensity conflicts when employment of NBC weapons or exposure to toxic industrial chemicals is likely.

Navy

The JSGPM shall provide Navy units with protective masks to provide for increased force protection. It shall protect against NBC *agents* as part of *MOPP* and thereby increase combat effectiveness. The JSGPM shall be employed under all typical battlefield conditions expected during high, medium, and low intensity conflicts when employment of NBC weapons or exposure to toxic industrial chemicals is likely. The Navy requires the JSGPM to operate concurrently during normal operating and environmental conditions, which shall include both interior and exterior spaces and areas, when employment of NBC weapons or exposure to toxic industrial chemicals is likely.

PERFORMANCE REQUIREMENTS

Mask Protection.

System Agent Testing.

[5] @ The mask system and accessories shall provide continuous above the neck, eye, respiratory and skin protection against vapor, aerosol, particulate, and liquid threat *agents* for 24 {36} hours.

Protection Factor.

[6] The mask shall provide an oronasal and eye *protection factor* of 10,000:1 (minimum) to the user population when worn with and without optical correction, with and without protective headgear and hood, or with or without all other accessories.

Fit Factor.

[7] The mask shall provide a *fit factor* of 6,667:1 (minimum) to the user population when worn with and without optical correction and with or without protective headgear and hood, or with or without all other accessories.

Filter Protection.

Chemical Agents.

[9] The filter shall protect against field concentrations of all military *agents*.

Biological Agents and Radioactive Fallout Particles.

[10] The filter shall protect against all *biological agents* and *radioactive fallout particles*.

Toxic Industrial Materials (TIMs).

[11] The filtration sub-system shall protect against all *Toxic Industrial Materials* including protection for the Toxic Industrial Chemicals identified in GROUP 1 {GROUP2} of Appendix G.

Protection Test Methods.

Mask System Protection.

System Agent Testing.

Testing shall be conducted by a Government approved source. System agent testing of the assembled mask shall be tested in accordance with Appendix B.

Protection Factor.

Testing shall be conducted by a Government approved source in accordance with Appendix A.

Fit Factor.

Testing shall be conducted using the M41 Protection Assessment Test System or equivalent quantitative fit test device. Testing procedures shall be similar to those used for *protection factor* testing except that subjects shall be trained and fit by a trained NBC specialist, but *donned* by the subject.

Filter Protection.

System Agent Testing.

Testing shall be conducted by a Government approved source. System agent testing of the filter assembled to the mask shall be tested in accordance with Appendix B.

Filter Life.

Chemical Agents.

Testing shall be conducted by a Government approved source. Gas life for CK, AC, CG, and SA shall be accomplished using a Q95 All Purpose Gas Life Tester or equivalent. Testing for GB and DMMP shall be accomplished using a Q224 Fifty Liter Per Minute Gas Life Tester or equivalent. Conditions for exposure are shown on Table 4.

Table 4. Filter Gas Life Test Conditions

Agent	Conditions
Agent: Sarin (GB) Initial: 150,000 Ct , minimum After 1 year: 40,000 Ct , minimum	Challenge concentration: 4,000 +/- 200 mg/m^3 Flow: 50.0 +/- 1.0 l/min, constant Temperature: 24 + 2 C Relative Humidity: 50 +/- 5 percent End-Point concentration: 0.04 mg/m^3 Pre-Equilibrium: None.
Agent: Cyanogen Chloride (CK) Initial: 40,000 Ct , minimum After 1 year: 20,000 Ct , minimum	Challenge concentration: 4,000 +/- 200 mg/m^3 Flow: 50.0 +/- 1.0 l/min., simulated breather Flow at 33 +/- 2 cycles/min Temperature: 24 + 2 C Relative Humidity: 80 +/- 3 percent End Point concentration: 8 mg/m^3 Pre-equilibrium: 80 percent relative humidity @ 27 +/- 5 C
Agent: Hydrocyanic Acid (AC) Initial: 40,000 Ct , minimum After 1 year: 20,000 Ct , minimum	Challenge concentration: 4,000 +/- 200 mg/m^3 Flow: 50.0 +/- 1.0 l/min, constant Temperature: 24 + 2 C Relative Humidity: 50 +/- 5 percent End-Point concentration: 4 mg/m^3 (AC) and/or 8 mg/m^3 (Cyanogen) Pre-Equilibrium: None.
Agent: Phosgene (CG)	Challenge concentration: 20,000 +/- 500

Initial: 150,000 C_t , minimum After 1 year: 40,000 C_t , minimum	mg/m^3 Flow: 50.0 +/- 1.0 l/min, constant Temperature: 24 + 2 C Relative Humidity: 50 +/- 5 percent End-Point concentration: 8 mg/m^3 Pre-Equilibrium: None.
Agent: Arsine (SA) Initial: 40,000 C_t , minimum After 1 year: 20,000 C_t , minimum	Challenge concentration: 10,000 +/- 500 mg/m^3 Flow: 50.0 +/- 1.0 l/min, constant Temperature: 24 + 2 C Relative Humidity: 80 +/- 3 percent End-Point concentration: 10 mg/m^3 Pre-Equilibrium: 80 percent relative humidity @ 27 +/- 5 C
Simulant: Dimethylmethylphosphonate (DMMP) Initial: 150,000 C_t , minimum After 1 year: 40,000 C_t , minimum	Challenge concentration: 3,000 +/- 400 mg/m^3 Flow: 50.0 +/- 1.0 l/min, constant Temperature: 24 + 2 C Relative Humidity: 15 +/- 5 percent End-Point concentration: 0.04 mg/m^3 Pre-Equilibrium: None

Biological Agents and Radioactive Fallout Particles.

Particulate penetration shall be measured using a neat cold-nebulized dioctyl phthalate (DOP) or equivalent liquid particulate aerosol. The aerosol at 25+/-5C shall have a particle size distribution with a count median diameter (CMD) of 0.185 +/- 0.02 micrometers and a geometric standard deviation not exceeding 1.60 at the specified test conditions as determined using a scanning mobility particle sizer or equivalent. Penetration shall be measured at 50 liters per minute. Each specimen shall be challenged with a concentration not to exceed 200 milligrams per cubic meter. The efficiency of the filter system shall be monitored and recorded though out the test period using a Government approved forward light scattering photometer or equivalent. The test shall proceed until the minimum efficiency is achieved or until an aerosol mass of at least 200 +/- 5 mg has contacted the filter system. If the filter efficiency is decreasing when the 200 +/- 5 mg loading point is reached, the test shall be continued until there is no further decrease in efficiency. Penetration through the filter system shall not exceed 0.01 percent (maximum).

Toxic Industrial Materials (TIMs).

Testing for TIMs shall be tested using a Government approved source and the test conditions in Table 5.

Table 5. Filter Gas Life Test Conditions

Toxic Industrial Chemical	Conditions
<p>TIM: Fuming Nitric Acid</p> <p>Initial: 5600 {40,000} C_t, minimum</p> <p>After 1 year: 5600 {40,000} C_t, minimum</p>	<p>Challenge concentration: 375 mg/m³ (NO₂)</p> <p>End-Point concentration: 9 mg/m³ NO₂ and 30 mg/m³ NO</p> <p>Flow: 50.0 +/- 1.0 l/min</p> <p>Temperature: 24 +/- 2 C</p> <p>Relative Humidity: 80 +/- 3 percent</p> <p>Pre-Equilibrium: 80 percent RH @ 27 +/- 5 C</p>
<p>TIM: Ammonia</p> <p>Initial: 42,000 C_t, minimum</p> <p>After 1 year: 42,000 C_t, minimum</p>	<p>Challenge concentration: 1000 mg/m³</p> <p>End-Point concentration: 35 mg/m³</p> <p>Flow: 50.0 +/- 1.0 l/min</p> <p>Temperature: 24 +/- 2 C</p> <p>Relative Humidity: 80 +/- 3 percent, 15 +/- 3 percent</p> <p>Pre-Equilibrium: None (< 15 % RH), 80 percent RH @ 27 +/- 5 C (80 % RH)</p>
<p>TIM: Carbon Disulfide</p> <p>Initial: 15,000 {40,000} C_t, minimum</p> <p>After 1 year: 15,000 {40,000} C_t, minimum</p>	<p>Challenge concentration: 1000 mg/m³</p> <p>End-Point concentration: 60 mg/m³</p> <p>Flow: 50.0 +/- 1.0 l/min</p> <p>Temperature: 24 +/- 2 C</p> <p>Relative Humidity: 80 +/- 3 percent</p> <p>Pre-Equilibrium: 80 percent RH @ 27 +/- 5 C</p>
<p>TIM: Ethylene oxide</p> <p>Initial: 40,000 {108,000} C_t, minimum</p> <p>After 1 year: 40,000 {108,000} C_t, minimum</p>	<p>Challenge concentration: 1000 mg/m³</p> <p>End-Point concentration: 1.8 mg/m³</p> <p>Flow: 50.0 +/- 1.0 l/min,</p> <p>Temperature: 24 +/- 2 C</p> <p>Relative Humidity: 80 +/- 3 percent</p> <p>Pre-Equilibrium: 80 percent RH at 27 +/- 5 C</p>
<p>TIM: Formaldehyde</p> <p>Initial: 25,000 {75,000} C_t, minimum</p> <p>After 1 year: 25,000 {75,000} C_t, minimum</p>	<p>Challenge Concentration: 1000 mg/m³</p> <p>End-Point Concentration: 1.2 mg/m³</p> <p>Flow: 50.0 +/- 1.0 l/min</p> <p>Temperature: 24 +/- 2 C</p> <p>Relative Humidity: less than 15 percent and 80 +/- 3 percent</p> <p>Pre-Equilibrium: None (< 15 % RH), 80 percent RH @ 27 +/- 5 C (80 % RH)</p>

3. APPENDIX G – INDUSTRIAL CHEMICAL HAZARD INDEX RANKING

THRESHOLD GROUP 1		OBJECTIVE GROUP 2			
Ammonia	Tungsten hexafluoride	Acrolein	Chlorine trifluoride	Hydrogen selenide	Phosphorus oxychloride
Arsine		Acrylonitrile	Chloroacetaldehyde	Hydrogen iodide	Phosphorus pentafluoride
Boron trichloride		Allyl alcohol	Chloroacetone	Iron pentacarbonyl	Sec-butyl chloroformate
Boron trifluoride		Allyl amine	Chloroacetonitrile	Isobutyl chloroformate	Selenium hexafluoride
Carbon disulfide		Allyl chlorocarbonate	Chloroacetyl chloride	Isopropyl isocyanate	Silicon tetrafluoride
Chlorine		Allyl isothiocyanate	Chlorosulfonic acid	Methanesulfonyl chloride	Stibine
Diborane		Arsenic trichloride	Crotonaldehyde	Methyl bromide	Sulfur trioxide
Ethylene oxide		Bromine	Cyanogen	Methyl chloroformate	Sulfuryl chloride
Fluorine		Bromine chloride	Diketene	Methyl chlorosilane	Sulfuryl fluoride
Formaldehyde		Bromine pentafluoride	1,2-dimethyl hydrazine	Methyl hydrazine	Tellurium hexafluoride
Hydrogen bromide		Boron tribromide	Dimethyl sulfate	Methyl mercaptan	Ter-octyl mercaptan
Hydrogen chloride		Bromine trifluoride	Diphenylmethane-4-diisocyanate	n-butyl chloroformate	Tert-butyl isocyanate
Hydrogen cyanide		Carbon monoxide	Ethyl chloroformate	n-butyl isocyanate	Tetraethyl lead
Hydrogen fluoride		Carbonyl fluoride	Ethyl chlorothioformate	Nitric oxide	Tetraethyl pyrophosphate
Hydrogen sulfide		Carbonyl sulfide	Ethylene dibromide	Nitrogen dioxide	Tetramethyl lead
Nitric acid, fuming		Chlorine pentafluoride	Ethyl phosphonothioic dichloride	n-propyl chloroformate	Titanium tetrachloride
Phosgene			Ethyl phosphonous	Parathion	Toluene 2,4-diisocyanate

			dichloride		
Phosphorous trichloride			Ethylene imine	Perchloromethyl mercaptan	Toluene 2,6-diisocyanate
Sulfur dioxide			Hexachlorocyclopentadiene	Phosphine	Trichloroacetyl chloride
Sulfuric acid					Trifluoroacetyl chloride



National Institute of Justice

Law Enforcement and Corrections Standards and Testing Program

Guide for the Selection of Chemical Agent and Toxic Industrial Material Detection Equipment for Emergency First Responders

NIJ Guide 100-00

Volume I
June 2000



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SECTION 2.0

INTRODUCTION TO CHEMICAL AGENTS AND TOXIC INDUSTRIAL MATERIALS

The purpose of this section is to provide a description of chemical agents (CAs) and toxic industrial materials (TIMs). Section 2.1 provides the discussion of chemical agents and section 2.2 provides the discussion of TIMs.

2.1 Chemical Agents

Chemical agents are chemical substances that are intended for use in warfare or terrorist activities to kill, seriously injure, or seriously incapacitate people through their physiological effects. A chemical agent attacks the organs of the human body in such a way that it prevents those organs from functioning normally. The results are usually disabling or even fatal.

The most common chemical agents are the nerve agents, GA (Tabun), GB (Sarin), GD (Soman), GF, and VX; the blister agents, HD (sulfur mustard) and HN (nitrogen mustard); and the arsenical vesicants, L (Lewisite). Other toxic chemicals such as hydrogen cyanide (characterized as a chemical blood agent by the military) are included as TIMs under Section 2.2 of this guide.

2.1.1 Nerve Agents

This section provides an overview of nerve agents. A discussion of their physical and chemical properties, their routes of entry, and descriptions of symptoms is also provided.

2.1.1.1 Overview

Among lethal chemical agents, the nerve agents have had an entirely dominant role since World War II. Nerve agents acquired their name because they affect the transmission of impulses in the nervous system. All nerve agents belong to the chemical group of organo-phosphorus compounds; many common herbicides and pesticides also belong to this chemical group. Nerve agents are stable, easily dispersed, highly toxic, and have rapid effects when absorbed both through the skin and the respiratory system. Nerve agents can be manufactured by means of fairly simple chemical techniques. The raw materials are inexpensive but some are subject to the controls of the Chemical Weapons Convention and the Australia Group Agreement.

2.1.1.2 Physical and Chemical Properties

The nerve agents considered in this guide are:

- GA: A low volatility persistent chemical agent that is taken up through skin contact and inhalation of the substance as a gas or aerosol. Volatility refers to a substance's ability to become a vapor at relatively low temperatures. A highly volatile (non-persistent) substance poses a greater respiratory hazard than a less volatile (persistent) substance.

- GB: A volatile non-persistent chemical agent mainly taken up through inhalation.
- GD: A moderately volatile chemical agent that can be taken up by inhalation or skin contact.
- GF: A low volatility persistent chemical agent that is taken up through skin contact and inhalation of the substance either as a gas or aerosol.
- VX: A low volatility persistent chemical agent that can remain on material, equipment, and terrain for long periods. Uptake is mainly through the skin but also through inhalation of the substance as a gas or aerosol.

Nerve agents in the pure state are colorless liquids. Their volatility varies widely. The consistency of VX may be likened to motor oil and is therefore classified as belonging to the group of persistent chemical agents. Its effect is mainly through direct contact with the skin. GB is at the opposite extreme; being an easily volatile liquid (comparable with, e.g., water), it is mainly taken up through the respiratory organs. The volatilities of GD, GA, and GF are between those of GB and VX. Table 2-1 lists the common nerve agents and some of their properties. Water is included in the table as a reference point for the nerve agents.

Table 2-1. Physical Properties of Common Nerve Agents

Property	GA	GB	GD	GF	VX	Water
Molecular weight	162.3	140.1	182.2	180.2	267.4	18
Density, g/cm ³ *	1.073	1.089	1.022	1.120	1.008	1
Boiling-point, °F	464	316	388	462	568	212
Melting-point, °F	18	-69	-44	-22	< -60	32
Vapor pressure, mm Hg *	0.07	2.9	0.4	0.06	0.0007	23.756
Volatility, mg/m ³ *	610	22,000	3,900	600	10.5	23,010
Solubility in water, % *	10	Miscible with water	2	~2	Slightly	NA

* at 77 °F

2.1.1.3 Route of Entry

Nerve agents, either as a gas, aerosol, or liquid, enter the body through inhalation or through the skin. Poisoning may also occur through consumption of liquids or foods contaminated with nerve agents.

The route of entry also influences the symptoms developed and, to some extent, the sequence of the different symptoms. Generally, the poisoning works fastest when the agent is absorbed through the respiratory system rather than other routes because the lungs contain numerous blood vessels and the inhaled nerve agent can rapidly diffuse into the blood circulation and thus reach the target organs. Among these organs, the respiratory system is one of the most important. If a person is exposed to a high concentration of nerve agent, e.g., 200 mg sarin/m³, death may occur within a couple of minutes.

The poisoning works slower when the agent is absorbed through the skin. Because nerve agents are somewhat fat-soluble, they can easily penetrate the outer layers of the skin, but it takes longer for the poison to reach the deeper blood vessels. Consequently, the first symptoms do not occur until 20 to 30 minutes after the initial exposure but subsequently, the poisoning process may be rapid if the total dose of nerve agent is high.

2.1.1.4 Symptoms

When exposed to a low dose of nerve agent, sufficient to cause minor poisoning, the victim experiences characteristic symptoms such as increased production of saliva, a runny nose, and a feeling of pressure on the chest. The pupil of the eye becomes contracted (miosis) which impairs night-vision. In addition, the capacity of the eye to change focal length is reduced and short-range vision deteriorates causing the victim to feel pain when trying to focus on nearby objects. This is accompanied by headache. Less specific symptoms are tiredness, slurred speech, hallucinations and nausea.

Exposure to a higher dose leads to more dramatic developments and symptoms are more pronounced. Bronchoconstriction and secretion of mucus in the respiratory system leads to difficulty in breathing and to coughing. Discomfort in the gastrointestinal tract may develop into cramping and vomiting, and there may be involuntary discharge of urine and defecation. There may be excessive salivating, tearing, and sweating. If the poisoning is moderate, typical symptoms affecting the skeletal muscles may be muscular weakness, local tremors, or convulsions.

When exposed to a high dose of nerve agent, the muscular symptoms are more pronounced and the victim may suffer convulsions and lose consciousness. The poisoning process may be so rapid that symptoms mentioned earlier may never have time to develop.

Nerve agents affect the respiratory muscles causing muscular paralysis. Nerve agents also affect the respiratory center of the central nervous system. The combination of these two effects is the direct cause of death. Consequently, death caused by nerve agents is similar to death by suffocation.

2.1.2 Blister Agents (Vesicants)

This section provides an overview of blister agents. A discussion of their physical and chemical properties, their routes of entry, and descriptions of symptoms is also provided.

2.1.2.1 Overview

There are two major families of blister agents (vesicants): sulfur mustard (HD) and nitrogen mustard (HN), and the arsenical vesicants (L). All blister agents are persistent and may be employed in the form of colorless gases and liquids. They burn and blister the skin or any other part of the body they contact. Blister agents are likely to be used to produce casualties rather than to kill, although exposure to such agents can be fatal.

2.1.2.2 Physical and Chemical Properties

In its pure state, mustard agent is colorless and almost odorless. It earned its name as a result of an early production method that resulted in an impure product with a mustard-like smell. Mustard agent is also claimed to have a characteristic odor similar to rotten onions. However, the sense of smell is dulled after only a few breaths so that the odor can no longer be distinguished. In addition, mustard agent can cause injury to the respiratory system in concentrations that are so low that the human sense of smell cannot distinguish them.

At room temperature, mustard agent is a liquid with low volatility and is very stable during storage. Mustard agent can easily be dissolved in most organic solvents but has negligible solubility in water. In aqueous solutions, mustard agent decomposes into non-poisonous products by means of hydrolysis but, since only dissolved mustard agent reacts, the decomposition proceeds very slowly. Oxidants such as chloramine (see page 24 for chloramine action), however, react violently with mustard agent, forming non-poisonous oxidation products. Consequently, these substances are used for the decontamination of mustard agent.

Arsenical vesicants are not as common or as stable as the sulfur or nitrogen mustards. All arsenical vesicants are colorless to brown liquids. They are more volatile than mustard and have fruity to geranium-like odors. These types of vesicants are much more dangerous as liquids than as vapors. Absorption of either vapor or liquid through the skin in adequate dosage may lead to systemic intoxication or death. The physical properties of the most common blister agents are listed in Table 2-2. Water is included in the table as a reference point for the blister agents.

Table 2-2. Physical Properties of Common Blister Agents

Property	HD	HN-1	HN-2	HN-3	L	Water
Molecular weight	159.1	170.1	156.1	204.5	207.4	18
Density, g/cm ³	1.27 at 68°F	1.09 at 77°F	1.15 at 68°F	1.24 at 77°F	1.89 at 68°F	1 at 77°F
Boiling-point, °F	421	381	167 at 15 mm Hg	493	374	212
Freezing-point, °F	58	-61.2	-85	-26.7	64.4 to 32.18	32
Vapor pressure, mm Hg	0.072 at 68°F	0.24 at 77°F	0.29 at 68°F	0.0109 at 77°F	0.394 at 68°F	23.756 at 77°F
Volatility, mg/m ³	610 at 68°F	1520 at 68°F	3580 at 77°F	121 at 77°F	4480 at 68°F	23,010 at 77°F
Solubility in water, %	<1%	Sparingly	Sparingly	Insoluble	Insoluble	NA

2.1.2.3 Route of Entry

Most blister agents are relatively persistent and are readily absorbed by all parts of the body. Poisoning may also occur through consumption of liquids or foods contaminated with blister agents. These agents cause inflammation, blisters, and general destruction of tissues. In the form of gas or liquid, mustard agent attacks the skin, eyes, lungs, and gastro-intestinal tract. Internal organs, mainly blood-generating organs, may also be injured as a result of mustard agent being taken up through the skin or lungs and transported into the body. Since mustard agent gives no immediate symptoms upon contact, a delay of between two and twenty-four hours may occur before pain is felt and the victim becomes aware of what has happened. By then, cell damage has already occurred. The delayed effect is a characteristic of mustard agent.

2.1.2.4 Symptoms

In general, vesicants can penetrate the skin by contact with either liquid or vapor. The latent period for the effects from mustard is usually several hours (the onset of symptoms from vapors is 4 to 6 hours and the onset of symptoms from skin exposure is 2 to 48 hours). There is no latent period for exposure to Lewisite.

Mild symptoms of mustard agent poisoning may include aching eyes with excessive tearing, inflammation of the skin, irritation of the mucous membranes, hoarseness, coughing and sneezing. Normally, these injuries do not require medical treatment.

Severe injuries that are incapacitating and require medical care may involve eye injuries with loss of sight, the formation of blisters on the skin, nausea, vomiting, and diarrhea together with severe difficulty in breathing. Severe damage to the eye may lead to the total loss of vision.

The most pronounced effects on inner organs are injury to the bone marrow, spleen, and lymphatic tissue. This may cause a drastic reduction in the number of white blood cells 5-10 days after exposure, a condition very similar to that after exposure to radiation. This reduction of the immune defense will complicate the already large risk of infection in people with severe skin and lung injuries.

The most common cause of death as a result of mustard agent poisoning is complications after lung injury caused by inhalation of mustard agent. Most of the chronic and late effects from mustard agent poisoning are also caused by lung injuries.



2.2 Toxic Industrial Materials

This section provides a general overview of TIMs as well as a list of the specific TIMs considered in this guide. Since the chemistry of TIMs is so varied, it is not feasible to discuss specific routes of entry and descriptions of symptoms.

Toxic industrial materials, or TIMs, are chemicals other than chemical warfare agents that have harmful effects on humans. TIMs, often referred to as toxic industrial chemicals, or TICs, are used in a variety of settings such as manufacturing facilities, maintenance areas, and general storage areas. While exposure to some of these

chemicals may not be immediately dangerous to life and health (IDLH), these compounds may have extremely serious effects on an individual's health after multiple low-level exposures.

2.2.1 General

A TIM is a *specific type* of industrial chemical i.e., one that has a LCt₅₀ value (lethal concentration for 50% of the population multiplied by exposure time) less than 100,000 mg-min/m³ in any mammalian species and is produced in quantities exceeding 30 tons per year at one production facility. Although they are not as lethal as the highly toxic nerve agents, their ability to make a significant impact on the populace is assumed to be more related to the amount of chemical a terrorist can employ on the target(s) and less related to their lethality. None of these compounds are as highly toxic as the nerve agents, but they are produced in very large quantities (multi-ton) and are readily available; therefore, they pose a far greater threat than chemical agents. For instance, sulfuric acid is not as lethal as the nerve agents, but it is easier to disseminate large quantities of sulfuric acid because of the large amounts that are manufactured and transported every day. It is assumed that a balance is struck between the lethality of a material and the amount of materials produced worldwide. Materials such as the nerve agents are so lethal as to be in a special class of chemicals.

Because TIMs are less lethal than the highly toxic nerve agents, it is more difficult to determine how to rank their potential for use by a terrorist. Physical and chemical properties for TIMs such as ammonia, chlorine, cyanogen chloride, and hydrogen cyanide are presented in Table 2-3. Water is included in the table as a reference point for the TIMs. The physical and chemical properties for the remaining TIMs identified in this guide can be found in *International Task Force 25: Hazard From Industrial Chemicals Final Report*, April 1998. (See detailed reference in Appendix B).

Table 2-3. Physical and Chemical Properties of TIMs

Property	Ammonia	Chlorine	Cyanogen Chloride	Hydrogen Cyanide	Water
Molecular weight	17.03	70.9	61.48	27.02	18
Density, g/cm ³	0.00077 at 77°F	3.214 at 77°F	1.18 at 68°F	0.990 at 68°F	1 at 77°F
Boiling-point, °F	-28	-30	55	78	212
Freezing-point, °F	-108	-150	20	8	32
Vapor pressure, mm Hg at 77°F	7408	5643	1000	742	23.756
Volatility, mg/m ³	6,782,064 at 77°F	21,508,124 at 77°F	2,600,000 at 68°F	1,080,000 at 77°F	23,010 at 77°F
Solubility in water, %	89.9	1.5	Slightly	Highly soluble	NA

2.2.2 TIM Rankings

TIMs are ranked into one of three categories that indicate their relative importance and assist in hazard assessment. Table 2-4 lists the TIMs with respect to their Hazard Index Ranking (High, Medium, or Low Hazard).²

2.2.2.1 High Hazard

High Hazard indicates a widely produced, stored or transported TIM that has high toxicity and is easily vaporized.

2.2.2.2 Medium Hazard

Medium Hazard indicates a TIM that may rank high in some categories but lower in others such as number of producers, physical state, or toxicity.

2.2.2.3 Low Hazard

A Low Hazard overall ranking indicates that this TIM is not likely to be a hazard unless specific operational factors indicate otherwise.

² International Task Force 25: Hazard From Industrial Chemicals Final Report, April 1998.

Table 2-4. TIMs Listed By Hazard Index

High	Medium	Low
Ammonia	Acetone cyanohydrin	Allyl isothiocyanate
Arsine	Acrolein	Arsenic trichloride
Boron trichloride	Acrylonitrile	Bromine
Boron trifluoride	Allyl alcohol	Bromine chloride
Carbon disulfide	Allylamine	Bromine pentafluoride
Chlorine	Allyl chlorocarbonate	Bromine trifluoride
Diborane	Boron tribromide	Carbonyl fluoride
Ethylene oxide	Carbon monoxide	Chlorine pentafluoride
Fluorine	Carbonyl sulfide	Chlorine trifluoride
Formaldehyde	Chloroacetone	Chloroacetaldehyde
Hydrogen bromide	Chloroacetonitrile	Chloroacetyl chloride
Hydrogen chloride	Chlorosulfonic acid	Crotonaldehyde
Hydrogen cyanide	Diketene	Cyanogen chloride
Hydrogen fluoride	1,2-Dimethylhydrazine	Dimethyl sulfate
Hydrogen sulfide	Ethylene dibromide	Diphenylmethane-4,4'-diisocyanate
Nitric acid, fuming	Hydrogen selenide	Ethyl chloroformate
Phosgene	Methanesulfonyl chloride	Ethyl chlorothioformate
Phosphorus trichloride	Methyl bromide	Ethyl phosphonothioic dichloride
Sulfur dioxide	Methyl chloroformate	Ethyl phosphonic dichloride
Sulfuric acid	Methyl chlorosilane	Ethyleneimine
Tungsten hexafluoride	Methyl hydrazine	Hexachlorocyclopentadiene
	Methyl isocyanate	Hydrogen iodide
	Methyl mercaptan	Iron pentacarbonyl
	Nitrogen dioxide	Isobutyl chloroformate
	Phosphine	Isopropyl chloroformate
	Phosphorus oxychloride	Isopropyl isocyanate
	Phosphorus pentafluoride	n-Butyl chloroformate
	Selenium hexafluoride	n-Butyl isocyanate
	Silicon tetrafluoride	Nitric oxide
	Stibine	n-Propyl chloroformate
	Sulfur trioxide	Parathion
	Sulfuryl chloride	Perchloromethyl mercaptan
	Sulfuryl fluoride	sec-Butyl chloroformate
	Tellurium hexafluoride	tert-Butyl isocyanate
	n-Octyl mercaptan	Tetraethyl lead
	Titanium tetrachloride	Tetraethyl pyrophosphate
	Trichloroacetyl chloride	Tetramethyl lead
	Trifluoroacetyl chloride	Toluene 2,4-diisocyanate
		Toluene 2,6-diisocyanate

Guidance for

Filtration and Air-Cleaning Systems to Protect Building Environments

from Airborne Chemical, Biological, or Radiological Attacks

Department of Health and Human Services

Centers for Disease Control and Prevention

National Institute for Occupational Safety and Health



April 2003



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Foreword

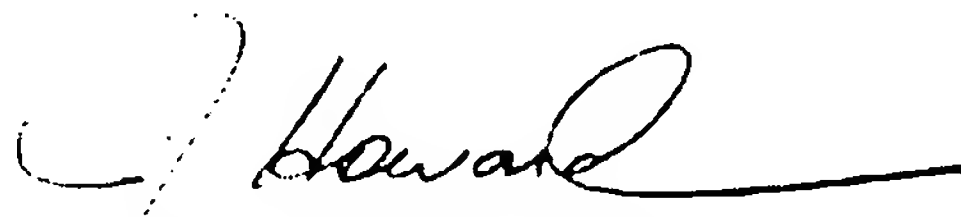
The Occupational Safety and Health Act of 1970 [Public Law 91-596] assures so far as possible every working man and woman in the Nation safe and healthful working conditions. The Act charges the National Institute for Occupational Safety and Health (NIOSH) with conducting research and making science-based recommendations to prevent work-related illness, injury, disability, and death.

On October 8, 2001, the President of the United States established by executive order the Office of Homeland Security (OHS), which is mandated "to develop and coordinate the implementation of a comprehensive national strategy to secure the United States from terrorist threats or attacks." In January 2002, the OHS formed the Interagency Workgroup on Building Air Protection under the Medical and Public Health Preparedness Policy Coordinating Committee of the OHS. The workgroup included representatives from agencies throughout the Federal Government, including NIOSH, which is part of the Department of Health and Human Services, Centers for Disease Control and Prevention. In May 2002, NIOSH, in cooperation with this workgroup, published *Guidance for Protecting Building Environments from Airborne Chemical, Biological, and Radiological Attacks*. This document provided building owners, managers, and maintenance personnel with recommendations to protect public, private, and government buildings from chemical, biological, or radiological attacks.

With U.S. workers and workplaces facing potential hazards associated with chemical, biological, or radiological terrorism, the occupational health and safety dimension of homeland security is

increasingly evident. As with most workplace hazards, preventive steps can reduce the likelihood and mitigate the impact of terrorist threats. This publication is the second NIOSH Guidance document aimed at protecting workplaces from these new threats. It provides detailed, comprehensive information on selecting and using filtration and air-cleaning systems in an efficient and cost-effective manner. Filtration systems can play a major role in protecting both buildings and their occupants.

Prevention is the cornerstone of public and occupational health. This document provides preventive measures that building owners and managers can implement to protect building air environments from a terrorist release of chemical, biological, or radiological contaminants. These recommendations, focusing on filtration and air cleaning, are part of the process to develop more comprehensive guidance. Working with partners in the public and private sectors, NIOSH will continue to build on this effort.



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Acknowledgments

This document was produced by the National Institute for Occupational Safety and Health (NIOSH) in cooperation with the White House Office of Homeland Security (OHS), Interagency Workgroup on Building Air Protection. The Interagency Workgroup on Building Air Protection was formed under the Medical and Public Health Preparedness Policy Coordinating Committee (PCC) of the OHS to focus on building air protection issues associated with an airborne chemical, biological, or radiological (CBR) attack. Workgroup participants provided guidance and direction at various times during this document's development. A list of the workgroup members is given in Appendix A. This document was written by a group of Federal Government employees under the direction of CDR G. Scott Earnest, Ph.D., P.E., C.S.P. and CDR Michael G. Gressel, Ph.D., C.S.P. Contributing authors to the document and their agency affiliations are listed below.

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The contributions of Patrick F. Spahn of the U.S. Department of State and Joseph E. Fernback and CAPT William G. Lotz of NIOSH are also gratefully acknowledged. Anne Votaw, Pauline Elliott, Anne Stirnkorb, and Dick Carlson of NIOSH provided editorial support, produced the camera-ready copy, and prepared the graphics. Review and preparation for printing were performed by Penny Arthur.

Abbreviations

μm	micrometer or micron, one-millionth of a meter
AC	hydrogen cyanide; a blood agent*
ACGIH	American Conference of Governmental Industrial Hygienists
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
ASZM-TEDA	U.S. military carbon: copper-silver-zinc-molybdenum-triethylenediamine
BZ	3-quinuclidinyl benzilate; an incapacitating agent*
°C	degrees Celsius
CBR	chemical, biological, or radiological
CDC	Centers for Disease Control and Prevention
CFC	chlorinated fluorocarbons
CFR	Code of Federal Regulations
cfm	cubic feet per minute
CG	phosgene; a choking agent*
CIF	chemically impregnated fibers
CK	cyanogen chloride; a blood agent*
DARPA	Defense Advanced Research Projects Agency
EPA	Environmental Protection Agency
fpm	feet per minute
ft ²	square feet
GB	isopropyl methylphosphonofluoridate; a nerve agent (sarin)*
HAZMAT	hazardous materials
HD	bis-(2-chloroethyl) sulfide; (mustard gas)*
HEPA	high-efficiency particulate air
HVAC	heating, ventilating, and air-conditioning
IAST	Institute of Environmental Sciences and Technology
km/hr	kilometers per hour

*Military designation.

kW·h	kilowatt·hours
in.	inch
LSD	d-lysergic acid diethyl amide; an incapacitating agent
m/s	meters per second
m ²	square meters
m ² /g	square meters per gram
m ³ /min	cubic meters per minute
MERV	minimum efficiency reporting value
mm	millimeters
mph	miles per hour
MPPS	most penetrating particle size
N95	95% efficient respirator filter for use in a non-oil mist environment
NAFA	National Air Filtration Association
NFPA	National Fire Protection Association
NBC	nuclear, biological, and chemical
NIOSH	National Institute for Occupational Safety and Health
nm	nanometers, one-billionth of a meter
OHS	White House Office of Homeland Security
OPT	optical microscope
OSHA	Occupational Safety and Health Administration
Pa	pascals
PCC	Policy Coordinating Committee
PPE	personal protective equipment
ppm	parts per million
PSE	particle size efficiency
SA	arsine; a blood agent*
SEM	scanning electron microscope
TIC	toxic industrial chemical
TIM	toxic industrial material
VX	O-ethyl-S-(2-diisopropyl aminoethyl) methyl phosphonothiolate; a nerve agent*
yr	year(s)

*Military designation.

Definitions

aerosols: Solid and liquid airborne particles, typically ranging in size from 0.001 to 100 μm .

air cleaning: Removal of gases or vapors from the air.

air filtration: Removal of aerosol contaminants from the air.

airborne contaminants: Gases, vapors, or aerosols.

arrestance: Ability of a filter to capture a mass fraction of coarse test dust.

bioaerosol: A suspension of particles of biological origin.

breakthrough concentration: Saturation point of downstream contaminant buildup, which prevents the collection ability of sorbent to protect against gases and vapors.

breakthrough time: Elapsed time between the initial contact of the toxic agent at a reported challenge concentration on the upstream surface of the sorbent bed and the breakthrough concentration on the downstream side.

challenge concentration: Airborne concentration of the hazardous agent entering the sorbent.

channeling: Air passing through portions of the sorbent bed that offer low airflow resistance due to non-uniform packing, irregular particle sizes, etc.

chemisorption: Sorbent capture mechanism dependent on chemically active medium (involves electron transfer).

collection efficiency: Fraction of entering particles that are retained by the filter (based on particle count or mass).

composite efficiency value: Descriptive rating value for a clean filter to incrementally load different particle sizes.

critical bed depth: See: mass transfer zone.

diffusion: Particle colliding with a fiber due to random (Brownian) motion.

dust spot efficiency: Measurement of a filter's ability to remove large particles (the staining portion of atmospheric dust).

dust holding capacity: Measurement of the total amount of dust a filter is able to hold during a dust-loading test.

electrostatic attraction: Small particles attracted to fibers, and after being contacted, retained there by a weak electrostatic force.

electrostatic filter: A filter that uses electrostatically enhanced fibers to attract and retain particles.

filter bypass: Airflow around a filter or through an unintended path.

filter face velocity: Air stream velocity just prior to entering the filter.

filter performance: A description of a filter's collection efficiency, pressure drop, and dust-holding capacity over time.

gas: Formless fluids which tend to occupy an entire space uniformly at ordinary temperatures.

gas-phase filter: Composed of sorbent medium, e.g., natural zeolite, alumina-activated carbon, specialty carbons, synthetic zeolite, polymers.

impaction: Particle colliding with a fiber due to particle inertia.

interception: Particle colliding with a fiber due to particle size.

large particle: Particles greater than 1 micrometer in diameter.

life-cycle cost: Sum of all filter costs from initial investment to disposal and replacement, including energy and maintenance costs.

mass transfer zone: Adsorbent bed depth required to reduce the chemical vapor challenge to the breakthrough concentration.

mechanical filter collection mechanism: Governs particulate air filter performance.

packing density Ratio of fiber volume to total filter volume.

particulate filter: Collects aerosols only—mechanically or electrostatically.

- **fibrous:** Assembly of fibers randomly laid perpendicular to airflow.
- **high-efficiency:** Primarily used to collect particles <1 micrometer.
- **low-efficiency:** Primarily used to collect particles >1 micrometer.
- **mechanical:** Cotton, fiberglass, polyester, polypropylene, or numerous other fiber materials that collect particles.
- **polarized:** Contains electrostatically enhanced fibers.

particulate filter design: Flat-panel filter, pleated filter, pocket filter, renewable filter (*see 3.1*).

particle size efficiency: Descriptive value of filter performance loading based upon specific particle sizes.

personal protective equipment (PPE) Devices worn by workers to protect against environmental hazards (i.e. respirators, gloves, hearing protection, etc.).

physicochemical properties: Physical and chemical characteristics of sorbents (pore size, shape, surface area, affinities, etc.). Characteristics of sorbent medium, e.g., pore size, shape, surface area, etc.

pressure drop: The difference in static pressure measured at two locations in a ventilation system. A measure of airflow resistance through a filter.

release of CBR agent: Airborne chemical, biological, or radiological release.

residence time: Length of time that a hazardous agent spends in contact with the sorbent.

sorbent: Porous medium that collects gases and vapors only.

vapor: The gaseous form of substances that are normally solid or liquid at ambient temperatures.

vapor pressure: Partial pressure of a liquid's vapor required to maintain the vapor in equilibrium with the condensed liquid or solid.

Guidance for
**Filtration and Air-Cleaning Systems
to Protect Building Environments
from Airborne Chemical, Biological,
or Radiological Attacks**

1. SCOPE

THIS DOCUMENT DISCUSSES AIR-FILTRATION AND AIR-CLEANING ISSUES associated with protecting building environments from an airborne chemical, biological, or radiological (CBR) attack. It provides information about issues that should be considered when assessing, installing, and upgrading filtration systems—along with the types of threats that can be addressed by air-filtration and air-cleaning systems. It is intended to provide guidance regarding measures that may be taken to prepare for a potential CBR attack, rather than in response to an actual CBR event. The complex issues regarding response and cleanup in the aftermath of an actual CBR event are situation dependent and are beyond the scope of this guidance document.

This is a companion document to the previously released NIOSH document titled *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks*. That document provided a broad array of recommendations for protecting buildings, including physical security, heating, ventilating, and air-conditioning (HVAC) system operation, maintenance and training, and filtration. This document gives specific and detailed guidance for one area of concern—filtration and air cleaning. The intended audience includes those who are responsible for making the technical decisions to improve filtration in public, private, and governmental buildings, such as offices, retail facilities, schools, transportation terminals, and public venues (for example, sports arenas, malls, coliseums). While many aspects of this document may apply to residential buildings, it is not intended to address filtration questions pertinent to housing because of their different function, design, construction, and operational characteristics. Likewise, certain types of higher risk or special use facilities—such as industrial facilities, military facilities, selected laboratories, and hospital isolation areas—require special considerations that are beyond the scope of this guide. The likelihood of a specific building being targeted for terrorist activity is difficult to predict. As such, there is no specific formula that will determine a certain building's level of risk. You who own or manage buildings should seek appropriate assistance as described in this document to decide how to reduce your building's risk from a CBR attack* and how to mitigate the effects if such an attack should occur. References on conducting a threat assessment can be found at the end of the NIOSH document *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks*.

*Note: References to a release of CBR agent in this document will always refer to an airborne CBR release.

After assessing your building's risk, you may wish to consider ways to enhance your filtration system. This document will help you make informed decisions about selecting, installing, and maintaining enhanced air-filtration and air-cleaning systems—important options in providing building protection from a CBR attack. The given recommendations are not intended to be minimum requirements that should be implemented for every building. Rather, they will guide your decision-making effort about the appropriate protective measures to implement in your building. The decision to enhance filtration in a specific building should be based on the perceived risk associated with that building and its tenants, its engineering and architectural applicability and feasibility, and the cost.

While no building can be fully protected from a determined group or individual intent on releasing a CBR agent, effective air filtration and air cleaning can help to limit the number and extent of injuries or fatalities and make subsequent decontamination efforts easier.

2. INTRODUCTION

Terrorist activities have resulted in heightened awareness of the vulnerability of U.S. workplaces, schools, and other occupied buildings to chemical, biological, or radiological (CBR) threats. Of particular concern are a building's heating, ventilating, and air-conditioning (HVAC) systems, as they can become entry points and distribution systems for many hazardous contaminants, including CBR agents.

Properly designed, installed, and maintained air-filtration and air-cleaning systems can reduce the effects of a CBR agent release, either outside or within a building, by removing the contaminants from the building's air supply. You who are building owners, managers, designers, and maintenance personnel need reliable information about filtration and air-cleaning options. You need to know

(1) what types of air-filtration and air-cleaning systems are effective for various CBR agents, (2) what types of air-filtration and air-cleaning systems can be implemented in an existing HVAC system, (3) what types of air-filtration and air-cleaning systems can be incorporated into existing buildings when they undergo comprehensive renovation, and (4) how to properly maintain the air-filtration and air-cleaning systems installed in your building. Proper air filtration and air cleaning, combined with other protective measures documented and referenced in the previous National Institute for Occupational Safety and Health (NIOSH) *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks* and elsewhere, can reduce the risk and mitigate the consequences of a CBR attack.

Measures outlined in the current document also provide the side benefits of improved HVAC efficiency: increased building cleanliness, limited effects from accidental releases, and generally improved indoor-air quality. These measures may also prevent cases of respiratory infection and reduce exacerbations of asthma and allergies among building occupants. Together, these accrued benefits may improve your workforce productivity.

Air-filtration and air-cleaning systems can remove a variety of contaminants from a building's airborne environment. The effectiveness of a particular filter design or air-cleaning media will depend upon the nature of the contaminant. In this document, *air filtration* refers to removal of aerosol contaminants from the air, and *air cleaning* refers to the removal of gases or vapors from the air. Airborne contaminants are gases, vapors, or aerosols (small solid and liquid particles). It is important to realize that sorbents collect gases and vapors, but not aerosols; conversely, particulate filters remove aerosols, but not gases and vapors. The ability of a given sorbent to remove a contaminant depends upon the characteristics of the specific gas or vapor and other related factors. The efficiency of a particulate filter to remove aerosols

depends upon the size of the particles, in combination with the type of filter used and HVAC operating conditions. Larger-sized aerosols can be collected on lower-efficiency filters, but the effective removal of a small-sized aerosol requires a higher-efficiency filter. Discussions in later sections of this document provide guidance on selecting the proper filters and/or air-cleaning media for specific types of air contaminants.

In addition to proper filter or sorbent selection, several issues must be considered before installing or upgrading filtration systems:

- Filter bypass is a common problem found in many HVAC filtration systems. Filter bypass occurs when air—rather than moving through the filter—goes around it, decreasing collection efficiency and defeating the intended purpose of the filtration system. Filter bypass is often caused by poorly fitting filters, poor sealing of filters in their framing systems, missing filter panels, or leaks and openings in the air-handling unit between the filter bank and blower. By simply improving filter efficiency without addressing filter bypass, you provide little if any benefit.
- Cost is another issue affected by HVAC filtration systems. Life-cycle cost should be considered (initial installation, replacement, operating, maintenance, etc.). Not only are higher-efficiency filters and sorbent filters more expensive than the commonly used HVAC system filters but also fan units may need to be changed to handle the increased pressure drop associated with the upgraded filtration systems. Although improved filtration will normally come at a higher cost, you can partially offset many of these costs by the accrued benefits, such as cleaner and more efficient HVAC components and improved indoor environmental quality.
- The envelope of your building matters. Filtration and air cleaning affect only the air that passes through the filtration and air-cleaning device, whether it is outdoor air, re-circulated air, or a mixture

of the two. Outside building walls in residential, commercial, and institutional buildings are quite leaky, and the effect from negative indoor air pressures (relative to the outdoors) allows significant quantities of unfiltered air to infiltrate the building envelope. Field studies have shown that, unless specific measures are taken to reduce infiltration, as much air may enter a building through infiltration (unfiltered) as through the mechanical ventilation (filtered) system. Therefore, you cannot expect filtration alone to protect your building from an outdoor CBR release. This is particularly so for systems in which no make-up air or inadequate overpressure is present. Instead, you must consider air filtration in combination with other steps, such as building pressurization and envelope air tightness, to increase the likelihood that the air entering the building actually passes through the filtration and air-cleaning systems.

CBR agents may travel in the air as a gas or an aerosol. Chemical warfare agents with relatively high vapor pressure are gaseous, while many other chemical warfare agents could potentially exist in either state. Biological and radiological agents are largely aerosols. A diagram of the relative sizes of common air contaminants (e.g., tobacco smoke, pollen, dust) is shown in Figure 1. CBR agents could potentially enter a building through either an internal or external release.

Some health consequences from CBR agents are immediate, while others may take much longer to appear. CBR agents (e.g., arsine, nitrogen mustard gas, anthrax, radiation from a dirty bomb) can enter the body through a number of routes including inhalation, skin absorption, contact with eyes or mucous membranes, and ingestion. The amount of a CBR agent required to cause specific symptoms varies among agents; however, these agents are generally much more toxic than common indoor air pollutants. In many cases, exposure to extremely small quantities may be lethal. Symptoms are markedly different for the different classes of agents (chemical,

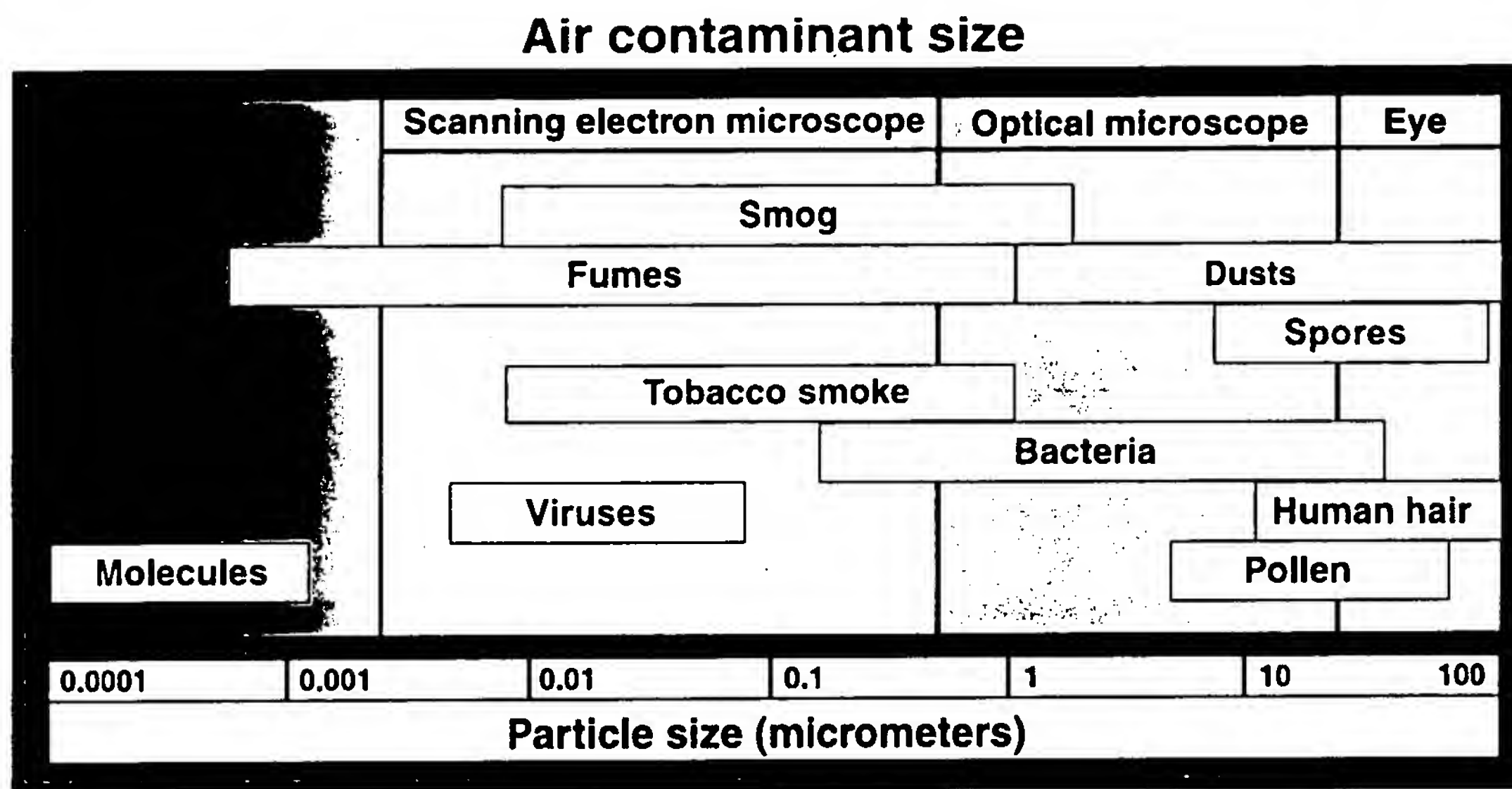


Figure 1. Common air contaminants and their relative sizes [Hinds 1982].

biological, or radiological). Symptoms resulting from exposure to chemical agents tend to occur quickly. Most chemical warfare agents (gases) are classified by their physiological effects, e.g., nerve, blood, blister, and choking. Toxic industrial chemicals (TICs) can also elicit similar types of effects. Conversely, symptoms associated with exposure to biological agents (bacteria, viruses) vary greatly with the agent and may take days or weeks to develop. These agents may result in high morbidity and mortality rates among the targeted population. Symptoms from exposure to ionizing radiation can include both long- and short-term effects. More detailed information regarding CBR agents is provided in Appendix B and can be found in the U.S. Army Field Manual 3-9, titled *Potential Military Chemical/Biological Agents and Compounds*.

3. FILTRATION AND AIR-CLEANING PRINCIPLES

Simply stated, filtration and air cleaning remove unwanted material from an air stream. For HVAC applications, this involves air filtration and, in some cases, air cleaning (for gas and vapor removal). The collection mechanisms for particulate filtration and air-cleaning systems are very different. The following description of the principles governing filtration and air cleaning briefly provides an understanding of the most important factors you should consider when selecting or enhancing your filtration system. A more detailed discussion of air-filtration principles can be found in the National Air Filtration Association's (NAFA) *Guide to Air Filtration* [NAFA 2001a] and the *ASHRAE Handbook: HVAC Systems and Equipment* [ASHRAE 2000].

3.1 Particulate Air Filtration

Particulate air filters are classified as either mechanical filters or electrostatic filters (electrostatically enhanced filters). Although there are many important performance differences between the two types of filters, both are fibrous media and used extensively in HVAC systems to remove particles, including biological materials, from the air. A fibrous filter is an assembly of fibers that are randomly laid perpendicular to the airflow (Figure 2). The fibers may range in size from less than 1 μm to greater than 50 μm in diameter. Filter packing density may range from 1% to 30%. Fibers are made from cotton, fiberglass, polyester, polypropylene, or numerous other materials [Davies 1973].

Fibrous filters of different designs are used for various applications. Flat-panel filters contain all of the media in the same plane. This design keeps the filter face velocity and the media velocity roughly the same. When pleated filters are used, additional filter media are

added to reduce the air velocity through the filter media. This enables the filter to increase collection efficiency for a given pressure drop. Pleated filters can run the range of efficiencies from a minimum efficiency reporting value (MERV) of 6 up to and including high-efficiency particulate air (HEPA) filters. With pocket filters, air flows through small pockets or bags constructed of the filter media. These filters can consist of a single bag or have multiple pockets, and an increased number of pockets increases the filter media surface area. As in pleated filters, the increased surface area of the pocket filter reduces the velocity of the airflow through the filter media, allowing increased collection efficiency for a given pressure drop. Renewable filters are typically low-efficiency media that are held on rollers. As the filter loads, the media are advanced or indexed, providing the HVAC system with a new filter [Spengler et al. 2000].



Figure 2. Scanning electron microscope image of a polyester-glass fiber filter.

Four different collection mechanisms govern particulate air filter performance: inertial impaction, interception, diffusion, and electrostatic attraction (Figure 3). The first three of these mechanisms apply mainly to mechanical filters and are influenced by particle size.

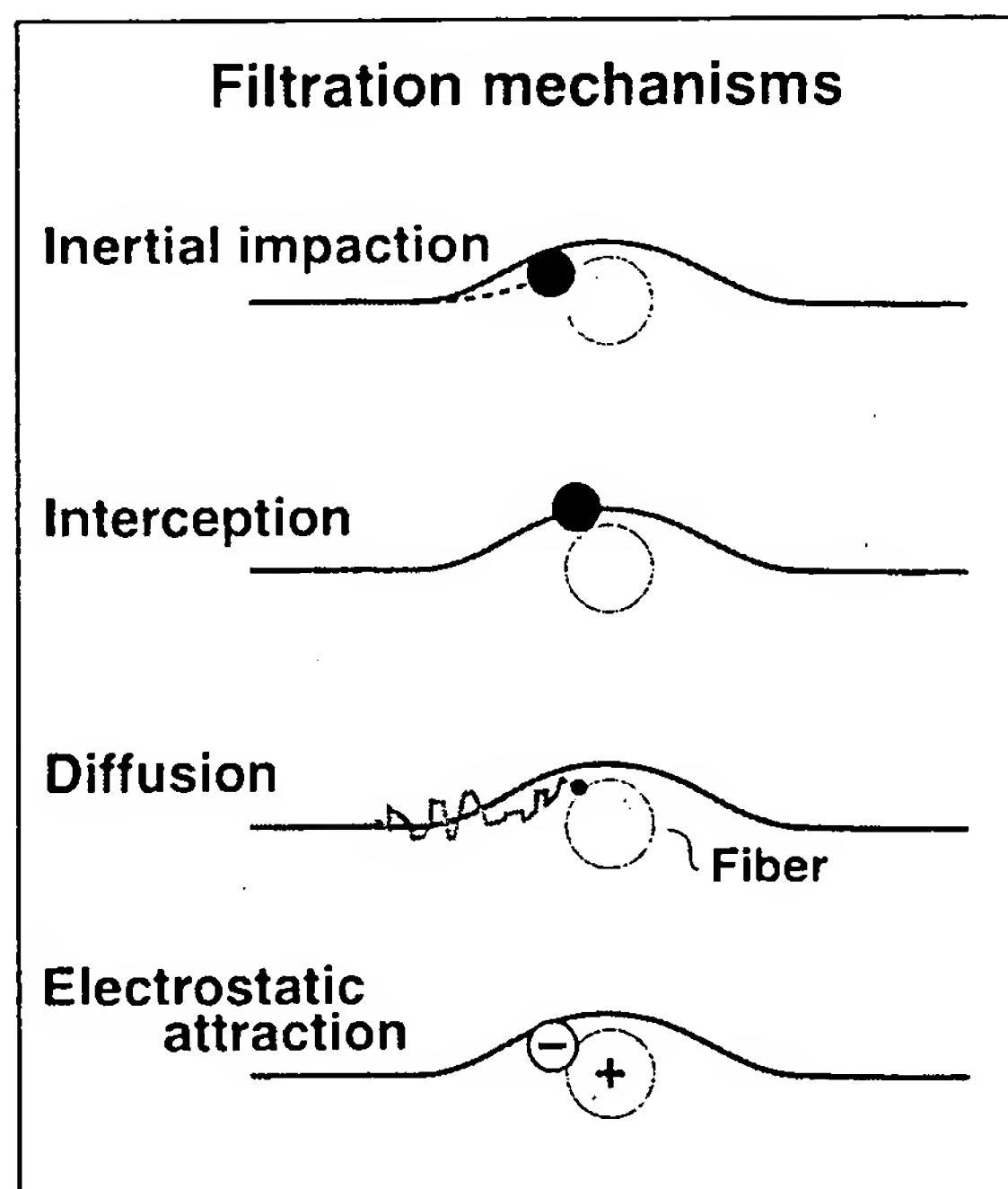


Figure 3. Four primary filter collection mechanisms.

- Impaction occurs when a particle traveling in the air stream and passing around a fiber, deviates from the air stream (due to particle inertia) and collides with a fiber.
- Interception occurs when a large particle, because of its size, collides with a fiber in the filter that the air stream is passing through.
- Diffusion occurs when the random (Brownian) motion of a particle causes that particle to contact a fiber.

- Electrostatic attraction, the fourth mechanism, plays a very minor role in mechanical filtration. After fiber contact is made, smaller particles are retained on the fibers by a weak electrostatic force.

Impaction and interception are the dominant collection mechanisms for particles greater than $0.2\ \mu\text{m}$, and diffusion is dominant for particles less than $0.2\ \mu\text{m}$. The combined effect of these three collection mechanisms results in the classic collection efficiency curve, shown in Figure 4.

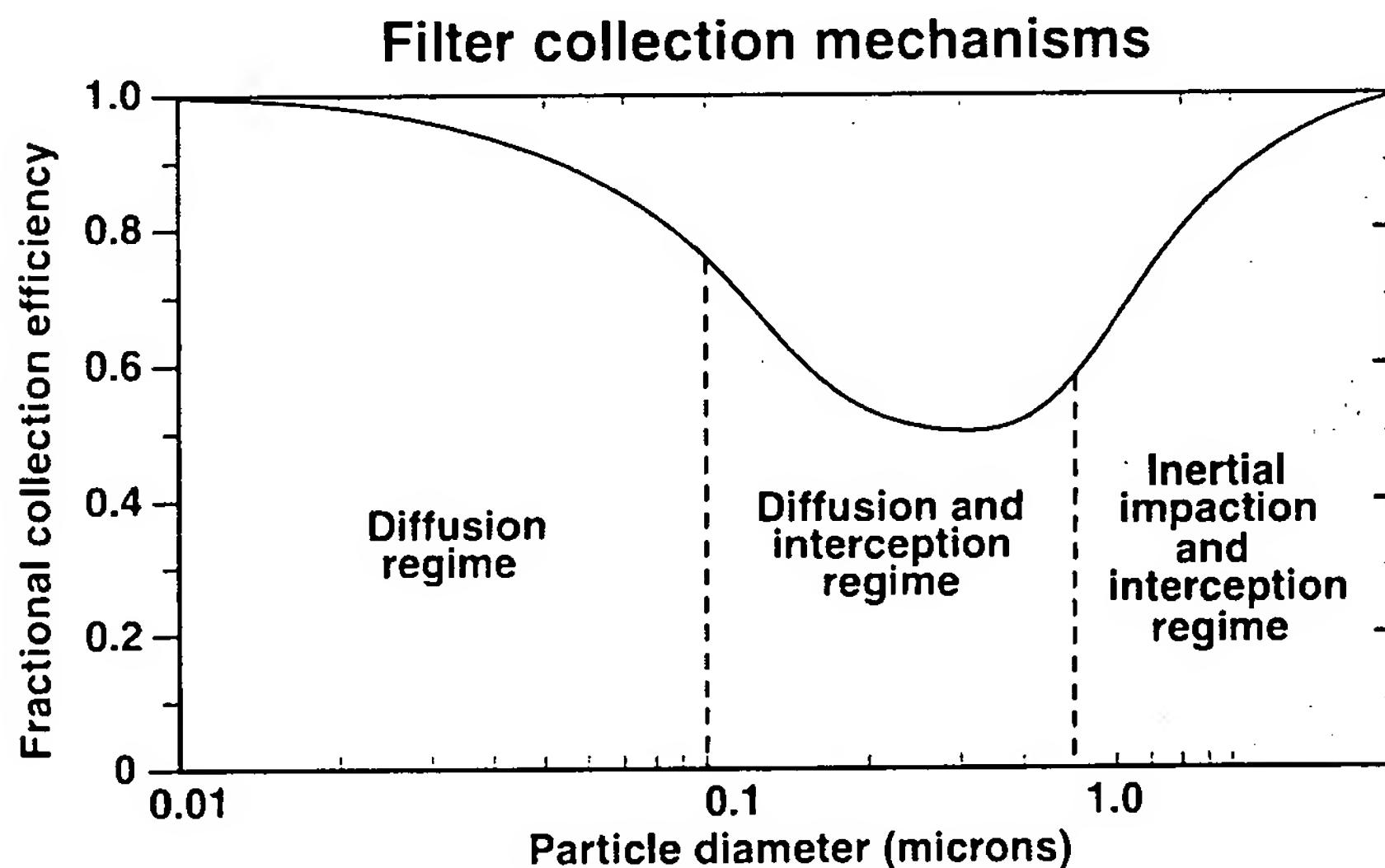


Figure 4. Fractional collection efficiency versus particle diameter for a mechanical filter.* The minimum filter efficiency will shift based upon the type of filter and flow velocity. (Note the dip for the most penetrating particle size and dominant collection mechanisms based upon particle size.)

*This figure is adapted from Lee et al. [1980].

Electrostatic filters contain electrostatically enhanced fibers, which actually attract the particles to the fibers, in addition to retaining them. Electrostatic filters rely on charged fibers to dramatically increase collection efficiency for a given pressure drop across the filter.

Electrostatically enhanced filters are different from electrostatic precipitators, also known as electronic air cleaners. Electrostatic precipitators require power and charged plates to attract and capture particles.

As mechanical filters load with particles over time, their collection efficiency and pressure drop typically increase. Eventually, the increased pressure drop significantly inhibits airflow, and the filters must be replaced. For this reason, pressure drop across mechanical filters is often monitored because it indicates when to replace filters.

Conversely, electrostatic filters, which are composed of polarized fibers, may lose their collection efficiency over time or when exposed to certain chemicals, aerosols, or high relative humidities. Pressure drop in an electrostatic filter generally increases at a slower rate than it does in a mechanical filter of similar efficiency. Thus, unlike the mechanical filter, pressure drop for the electrostatic filter is a poor indicator of the need to change filters. When selecting an HVAC filter, you should keep these differences between mechanical and electrostatic filters in mind because they will have an impact on your filter's performance (collection efficiency over time), as well as on maintenance requirements (change-out schedules).

Air filters are commonly described and rated based upon their collection efficiency, pressure drop (or airflow resistance), and particulate-holding capacity. Two filter test methods are currently used in the United States:

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 52.1-1992
- ASHRAE Standard 52.2-1999

Standard 52.1-1992 measures arrestance, dust spot efficiency, and dust holding capacity. *Arrestance* means a filter's ability to capture a mass fraction of coarse test dust and is suited for describing low- and medium-efficiency filters. Be aware that arrestance values may be high, even for low-efficiency filters, and do not adequately indicate the effectiveness of certain filters for CBR protection. *Dust spot efficiency* measures a filter's ability to remove large particles, those that tend to soil building interiors. *Dust holding capacity* is a measure of the total amount of dust a filter is able to hold during a dust-loading test.

ASHRAE Standard 52.2-1999 measures particle size efficiency (PSE). This newer standard is a more descriptive test, which quantifies filtration efficiency in different particle size ranges for a clean and incrementally loaded filter to provide a composite efficiency value. It gives a better determination of a filter's effectiveness to capture solid particulate as opposed to liquid aerosols. The 1999 standard rates particle-size efficiency results as a MERV between 1 and 20. A higher MERV indicates a more efficient filter. In addition, Standard 52.2 provides a table (see Table 1) showing minimum PSE in three size ranges for each of the MERV numbers, 1 through 16. Thus, if you know the size of your contaminant, you can identify an appropriate filter that has the desired PSE for that particular particle size. Figure 5 shows actual test results for a MERV 9 filter and the corresponding filter collection efficiency increase due to loading.

Table 1. Comparison of ASHRAE Standard 52.1 and 52.2

ASHRAE 52.2				ASHRAE 52.1		Particle size range, μm	Applications
	Particle size range			Test			
MERV	3 to 10 μm	1 to 3 μm	.3 to 1 μm	Arrestance	Dust spot		
1	< 20%	—	—	< 65%	< 20%	>10	residential light pollen, dust mites
2	< 20%	—	—	65–70%	< 20%		
3	< 20%	—	—	70–75%	< 20%		
4	< 20%	—	—	> 75%	< 20%		
5	20–35%	—	—	80–85%	< 20%	3.0–10	industrial, dust, molds, spores
6	35–50%	—	—	> 90%	< 20%		
7	50–70%	—	—	> 90%	20–25%		
8	> 70%	—	—	> 95%	25–30%		
9	> 85%	< 50%	—	> 95%	40–45%	1.0–3.0	industrial, Legionella, dust
10	> 85%	50–65%	—	> 95%	50–55%		
11	> 85%	65–80%	—	> 98%	60–65%		
12	> 90%	> 80%	—	> 98%	70–75%		
13	> 90%	> 90%	< 75%	> 98%	80–90%	0.3–1.0	hospitals, smoke removal, bacteria
14	> 90%	> 90%	75–85%	> 98%	90–95%		
15	> 90%	> 90%	85–95%	> 98%	~95%		
16	> 95%	> 95%	> 95%	> 98%	> 95%		
17	—	—	$\geq 99.97\%$	—	—	<0.3	clean rooms, surgery, chem-bio, viruses
18	—	—	$\geq 99.99\%$	—	—		
19	—	—	$\geq 99.999\%$	—	—		
20	—	—	$\geq 99.9999\%$	—	—		

Note: This table is adapted from ASHRAE [1999] and Spengler et al. [2000].

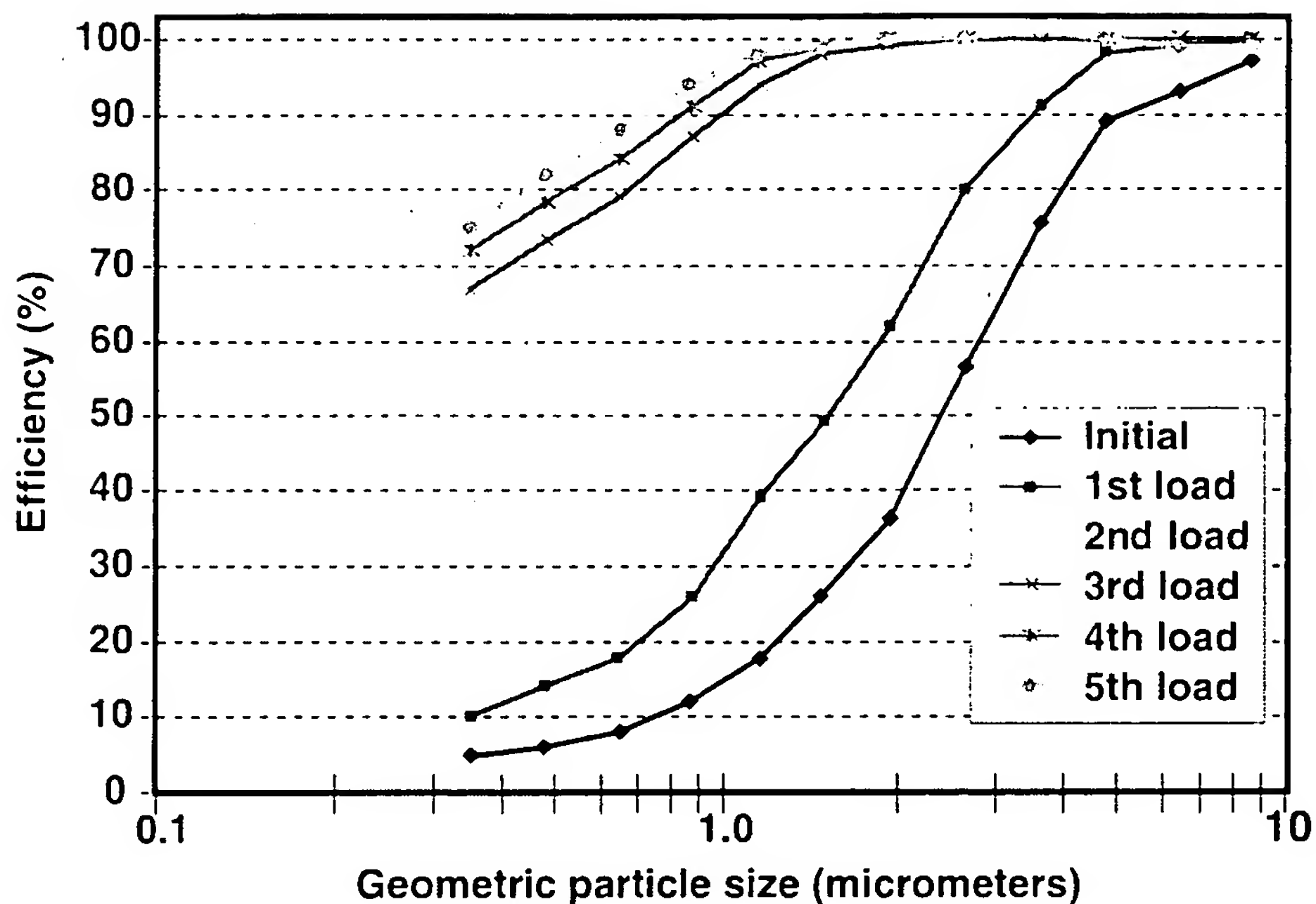


Figure 5. ASHRAE Standard 52.2 test data for a MERV 9 filter showing how collection efficiency increases as the filter loads.

3.2 Gas-Phase Air Cleaning

Some HVAC systems may be equipped with sorbent filters, designed to remove pollutant gases and vapors from the building environment. Sorbents use one of two mechanisms for capturing and controlling gas-phase air contaminants—physical adsorption and chemisorption. Both capture mechanisms remove specific types of gas-phase contaminants from indoor air. Unlike particulate filters, sorbents cover a wide range of highly porous materials (Figure 6), varying from simple clays and carbons to complexly engineered polymers. Many sorbents—not including those that are chemically active—can be regenerated by application of heat or other processes.

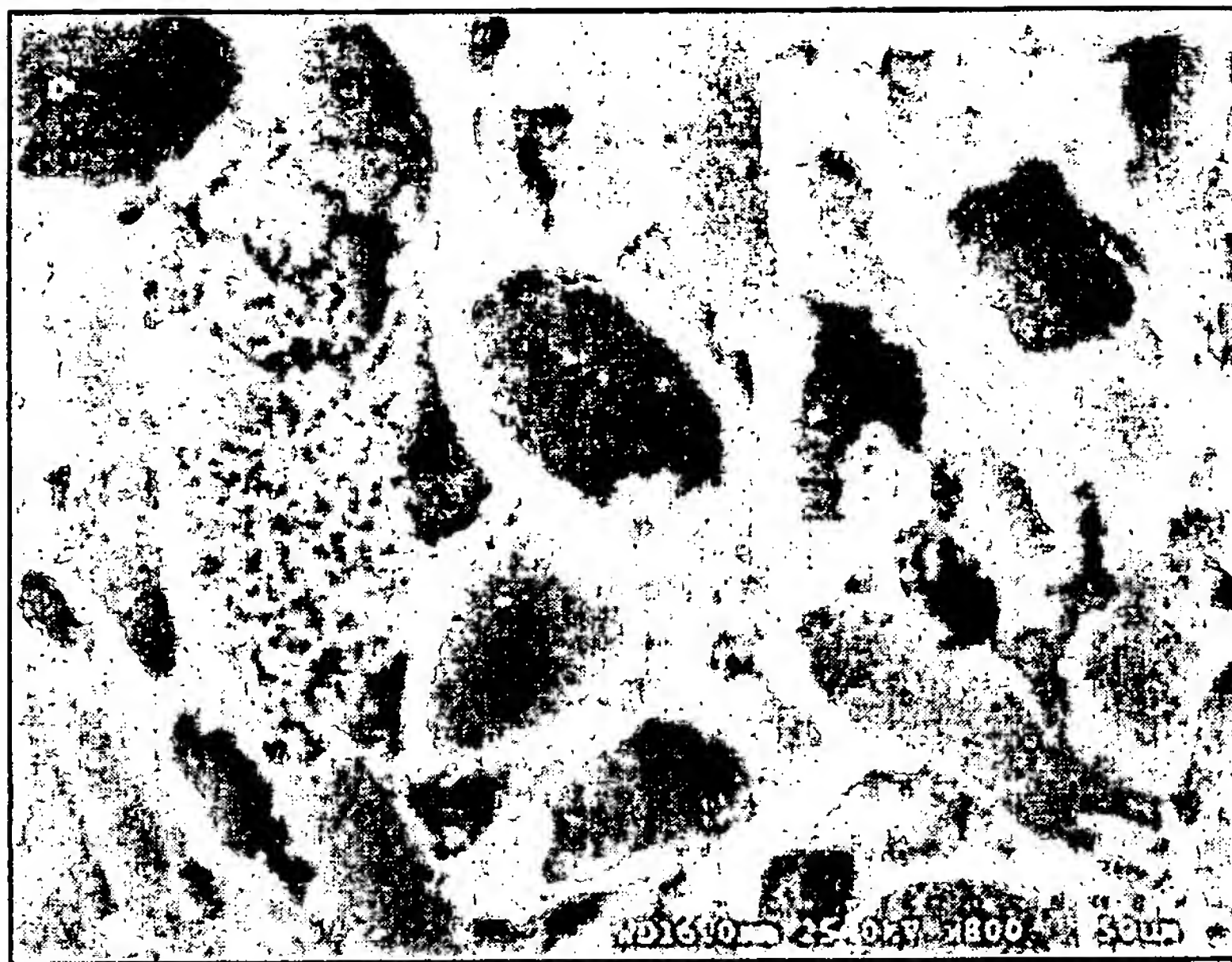


Figure 6. Scanning electron microscope image of activated carbon pores.

Understanding the precise removal mechanism for gases and vapors is often difficult due to the nature of the adsorbent and the processes involved. While knowledge of adsorption equilibrium helps in understanding vapor protection, sorbent performance depends on such properties as mass transfer, chemical reaction rates, and chemical reaction capacity. A more thorough discussion of gas-phase air-cleaning principles is provided in Appendix C of this document. Some of the most important parameters of gas-phase air cleaning include the following:

- **BREAKTHROUGH CONCENTRATION:** the downstream contaminant concentration, above which the sorbent is considered to be performing inadequately. Breakthrough concentration indicates the agent has broken through the sorbent, which is no longer giving the intended protection. This parameter is a function of loading history, relative humidity, and other factors.

- **BREAKTHROUGH TIME:** the elapsed time between the initial contact of the toxic agent at a reported challenge concentration on the upstream surface of the sorbent bed, and the breakthrough concentration on the downstream side of the sorbent bed.
- **CHALLENGE CONCENTRATION:** the airborne concentration of the hazardous agent entering the sorbent.
- **RESIDENCE TIME:** the length of time that the hazardous agent spends in contact with the sorbent. This term is generally used in the context of superficial residence time, which is calculated on the basis of the adsorbent bed volume and the volumetric flow rate.
- **MASS TRANSFER ZONE OR CRITICAL BED DEPTH:** interchangeably used terms, which refer to the adsorbent bed depth required to reduce the chemical vapor challenge to the breakthrough concentration. When applied to the challenge chemicals that are removed by chemical reaction, mass transfer is not a precise descriptor, but is often used in that context. The portion of the adsorbent bed not included in the mass transfer zone is often termed the capacity zone.

4. RECOMMENDATIONS REGARDING FILTER AND SORBENT SELECTION, OPERATIONS, UPGRADE, AND MAINTENANCE

Before selecting a filtration and air-cleaning strategy that includes a potential upgrade in response to perceived types of threats, develop an understanding of your building and its HVAC system. A vital part of this effort will be to evaluate your total HVAC system thoroughly. Assess how your HVAC system is designed and intended to operate and compare that to how it currently operates. In large buildings, this evaluation is likely to involve many different air-handling units and system components.

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